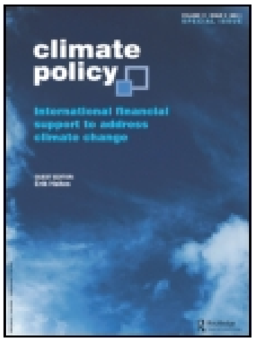

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RESEARCH ARTICLE

Global Triptych: a bottom-up approach for the differentiation of commitments under the Climate Convention

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Abstract

In the coming years the international debate on commitments for the second commitment period under the Kyoto Protocol will intensify. In this study, the Global Triptych approach is put forward as an input for international decision-making concerning the differentiation of commitments by 2020. It is a sector- and technology-oriented approach, and we calculated quantitative emission limitation objectives and global emissions starting from bottom-up information on long-term reduction opportunities. Central to the calculations were long-term sustainability targets for the year 2050, formulated for (1) energy efficiency in the energy-intensive industry, (2) greenhouse gas intensity of electricity production, and (3) per capita emissions in the domestic sectors. Calculated emission limitation objectives for 13 world regions ranged from about -30% to more than +200%. The ranking of world regions in the differentiation turned out to be independent of the levels chosen for the long-term sustainability targets. The objectives seem sufficient to maintain the long-term possibility of stabilizing atmospheric greenhouse gas concentrations at about 550 ppm CO_2-eq, but will require severe emission reductions. These may be relaxed to a certain degree if stabilization at 650 ppm CO_2-eq is aimed for. We conclude that the bottom-up character of the approach made it possible to examine important basic principles of the Climate Convention, including equity, the needs and circumstances of developing countries, cost-effectiveness and sustainable development.

Keywords: Burden sharing; Bottom-up; Equity; Sustainable development; Atmospheric stabilization

1. Introduction

The international differentiation of commitments under the United Nations Framework Convention on Climate Change (UNFCCC) is likely to be debated more intensively in the years ahead. The Kyoto Protocol stipulates (Article 3.9), that considerations regarding Annex I commitments for subsequent commitment periods shall be initiated not later than 2005. Recently, various proposals to differentiate such commitments have been put forward in the literature, and a great deal of attention has been given to

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viable ways of including non-Annex I countries in a future climate regime (UN, 1997a, 1997b, 1999, 2001; CSE, 1998; Gupta, 1999; Meyer, 2000; Berk and den Elzen, 2001; Blanchard *et al*., 2001; den Elzen, 2001; Gupta *et al*., 2001; Philibert and Pershing, 2001; Sijm *et al*., 2001).

At present much of the debate on effective mitigation strategies either focuses on cost-effective ways of complying with the Kyoto commitments, agreed on in a rather ad-hoc manner, or it concentrates on long-term stabilization levels for atmospheric greenhouse gases. Neither strategy provides much guidance for effective long-term mitigation strategies, the former being preoccupied with the short term and the latter being too abstract to be of much help in concrete policy formulation.

Whatever the point of departure may be, it is obvious that any approach to the differentiation of commitments should consider the basic principles for international climate policy as laid down in the Climate Convention. These include (1) the notion of equity and the 'common but differentiated responsibilities', (2) the specific needs and special circumstances of developing country Parties, (3) cost-effectiveness of measures, (4) a harmonization of climate change mitigation measures and sustainable development, and (5) a supportive and open international economic system.

In this article we aim to put forward an approach to the differentiation of commitments that takes into account most of the basic principles of the Convention. In our study we will take as a point of departure the Triptych approach to differentiation. This is a sector-based and technology-oriented approach that served to differentiate the EU's internal Kyoto target between its Member States (Blok *et al*., 1997; Phylipsen *et al*., 1998; Ringius, 1999). Based on the findings of more recent investigations (Groenenberg *et al*., 2001; Groenenberg, 2002) we propose a new differentiation scheme as a tool for supporting international decision-making on the quantification of emission limitation objectives.[1] We analyse an exploratory target-oriented calculation scheme, comprising all emitting sectors. In this scheme we will define global long-term sustainability targets for energy efficiency in the energy-intensive industry, for greenhouse gas intensity of electricity production and for per capita emissions in the domestic sectors. These comprise the **r**esidential and **c**ommercial sectors, **t**ransportation and **l**ight industry, and the remainder of fossil fuel related emissions. We will refer to these sectors as the RCTL sectors. Bottom-up information on reduction opportunities is used to set the level of the sustainability targets. We call our approach 'Global Triptych' to reflect its three convergence trajectories in the energy-using sectors.[2] We did not only single out three energy-using sectors, but also emissions from fossil fuel production, agriculture and deforestation, comprising both CO_2 and non-CO_2 emissions. In most of our calculations and results, however, deforestation emissions will be excluded for reasons which we will clarify later (section 2.6). In general, the Global Triptych approach allows for a certain growth in activity in the various sectors and considers advanced technological opportunities to minimize emissions. Allowed activity growth is based on medium growth projections for the various sectors.

The focus of the debate on post-Kyoto commitments is on the next one or two decades. However, an effective long-term climate regime needs to take into account mitigation opportunities in the longer term. Therefore two time horizons will be used in this study. We will calculate emission limitation objectives for the year 2020 using long-term sustainability targets. In formulating these long-term targets for technical improvement and the transition to low-carbon energy we will focus on the year 2050. Obviously this year is not as remote as the long-term horizon required for stabilizing atmospheric concentrations. The year 2050 is within the time horizon of at least today's youngest generation. Before 2050, however, there may well be some social and technological breakthroughs that succeed in restructuring current greenhouse gas emissions. On the assumption that technology development takes 10–20 years (Luiten, 2001) and that the lifetime of technologies, which determines long-term investment cycles, is 30 years, half a century should be sufficient time to make considerable headway in reducing greenhouse gas emissions. Obviously, targeted policies are necessary to make progress towards realizing these straightforward sustainability targets world-wide. Obstacles to meeting these targets may include low prices of energy and the export of second-hand and obsolete technologies to developing regions.

A decision support tool such as the one we put forward here seems to bear a strong resemblance to the building of a mitigation scenario, in which climate policies are assumed to restructure greenhouse gas emissions. Nevertheless, there are important differences.

First of all, unlike a mitigation scenario, an approach for differentiating commitments is designed specifically to serve as an input for negotiations on future allowed emissions. This means that it must be highly transparent and understandable for a non-expert audience. This puts limits on the complexity of such a differentiation approach. Inevitably, simplifications have to be made with respect to activity levels in various sectors of the economy, whereas in complex models such activity levels might be estimated in a more refined manner.

Secondly, a decision-support tool must offer some choices to the negotiator. In the Global Triptych this scope for choice crystallizes as the three long-term sustainability targets. At the same time, the number of choices must be restricted in order not to overwhelm the user with a large number of parameters whose value is difficult to assess without extensive knowledge of the field. Therefore some starting points must be made explicit.

Thirdly, our differentiation approach entails a number of very straightforward processes of convergence towards long-term sustainability targets. Contrary to many (though not all) mitigation scenarios, the calculated emissions result from a back-casting exercise. To quote Lempert and Schlesinger in their essay on robust mitigation strategies (2000), the question is not ‘what is likely to happen in the future?’ but rather ‘what actions should we take, given that we cannot predict the future?’ In the light of the latter question, long-term sustainability targets may well help to structure the debate on new commitments.

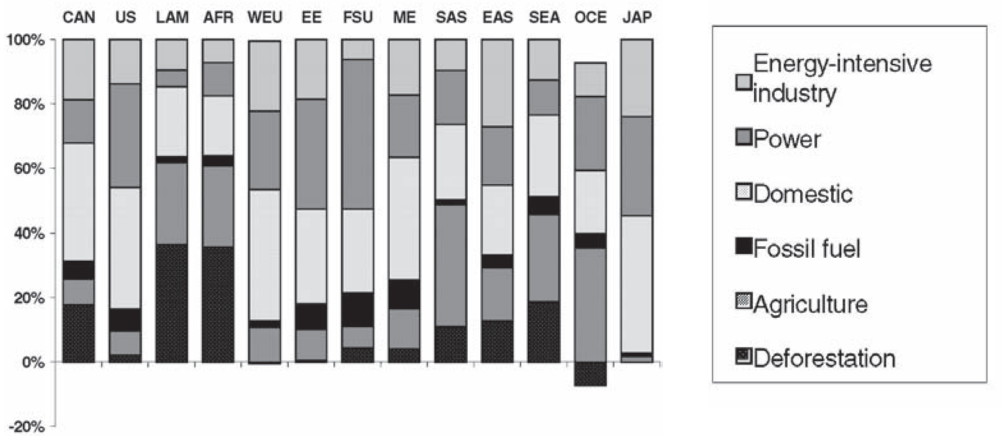
In this article we will elaborate the Global Triptych approach for 13 world regions, including both Annex I and non-Annex I countries. Global greenhouse gas emissions in 1995 amounted to 10 GtC-eq (37 $GtCO_2$-eq). Figure 1 shows their distribution over various sources world-wide and in the regions included in this study.

In section 2 we give a general description of various sectors of the Global Triptych approach. For each of these we indicate the factors on which growth allowances are based and explain how sectoral objectives are calculated. Section 3 deals with the resulting emission objectives in a base case for the 13 regions in the year 2020 and the accompanying global emission levels, and reports on a series of sensitivity analyses. In section 4 we assess calculated global emissions against the Convention’s ultimate objective of stabilizing atmospheric concentrations. We discuss to what extent our method agrees with the basic principles of the Climate Convention in section 5, and present conclusions in section 6. Note that a detailed argumentation of the data and assumptions in the approach is presented by Groenenberg (2002).

2. Description of the Global Triptych approach

2.1. The energy-intensive industry

The internationally oriented energy-intensive industry[3] has relatively high CO_2 emissions per monetary unit of production. Consequently, countries that rely to a large extent on this sector have higher CO_2 emissions than countries that are more dependent on services, light industry or agriculture. The



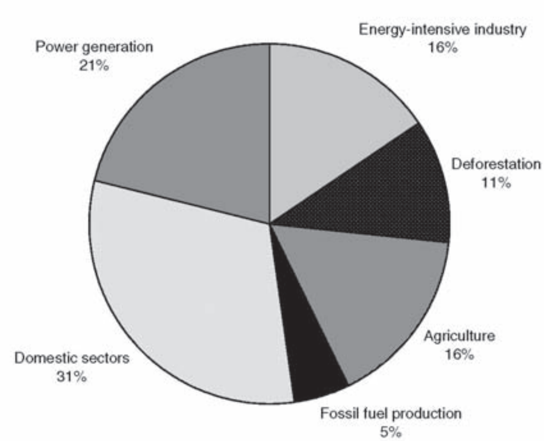


Figure 1. Contribution of sectors in 1995 to (left) global and (above) regional greenhouse gas emissions (excluding international aviation and marine bunkers). Energy transformation (e.g. refineries) other than power production is included in the energy-intensive industry. The domestic sectors include the residential and commercial sectors, transportation, and light industry. Energy-related CO_2 emissions in agriculture or during the production of fossil fuels are also included in the domestic sectors. Agriculture comprises CH_4 and N_2O only (IEA, 1997; IMAGE-team, 2001; Olivier, 2002). Note that Oceania has negative emissions from land-use change i.e. more carbon is sequestered in terrestrial sinks than emitted

international character of this sector means that countries lacking sizeable energy-intensive industries import goods from the energy-intensive industry in other countries and thus profit from other countries' efforts in this sector. Countries should not necessarily be penalized for having an energy-intensive industry, since they supply goods consumed by other countries. Non-CO_2 greenhouse gases in the energy-intensive industry amount to 8% of total greenhouse gas emissions in this sector. Our estimation of future growth in the energy-intensive industry is based on a detailed study of recent historical trends (Groenenberg, 2002).[4] From this study, projections follow for physical production per capita. These are 6%, 3.5%, 1% and 0.5% for the lowest income, upper low income, mid-income and high income countries, respectively. Total emissions growth in the energy-intensive industry between 1995 and 2020 can thus be modelled as a function of population growth, economic growth and these growth projections of per capita production (Figure 2, Table 1). Average projected growth factors over this period range between 1.2 and 1.4 for the OECD regions, around 5 for India and Africa, and are of the order of 2 for most other regions. Note that future industrial growth may be reduced somewhat if commodities are used more efficiently. As a criterion for determining (non-binding) sectoral objectives in the energy-intensive industry, we assume from the outset that levels of energy efficiency will converge at some point in the future. Energy efficiency can be

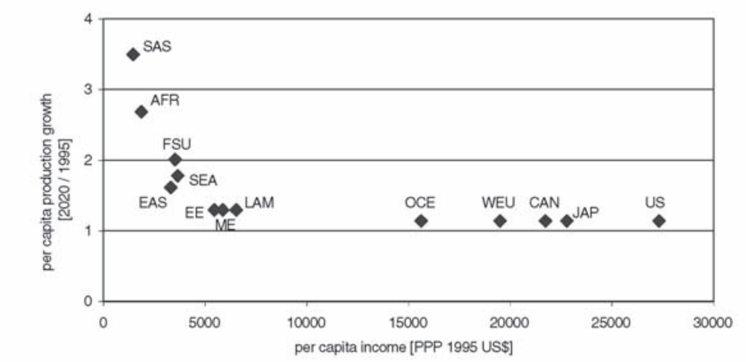


Figure 2. Average growth factors by 2020, compared with 1995 production levels, for per capita production levels in the energy-intensive industry, based on the method presented in Groenenberg (2002)

Table 1. Growth factors per capita (average) and total growth of physical production (average and range), for the year 2020 in relation to 1995 production levels in the energy-intensive industry, based on the method in Groenenberg (2002)

Region	Growth per capita	Total growth	Region	Growth per capita	Total growth
Canada	1.1	1.4 (1.4–1.4)[a]	Middle East	1.3	2.2 (2.1–2.3)
USA	1.1	1.4 (1.4–1.4)	South Asia	3.5	5.4 (4.8–6.6)
Latin America	1.3	1.8 (1.8–2.0)	East Asia	1.6	2.0 (1.9–2.3)
Africa	2.7	4.9 (4.6–5.1)	South East Asia	1.8	2.5 (2.2–3.0)
Western Europe	1.1	1.2 (1.2–1.3)	Oceania	1.1	1.3 (1.3–1.4)
Eastern Europe	1.3	1.3 (1.3–1.4)	Japan	1.1	1.2 (1.2–1.3)
Former Soviet Union	2.0	2.1 (1.9–2.5)	World	1.3	1.8 (1.7–1.9)

[a] Upper and lower values of this range are both between 1.35 and 1.44. Uncertainties allow only one decimal place to be given. Ranges are based on the various economic scenarios in Nakicenovic *et al.* (2000).

expressed by means of the Energy Efficiency Index (EEI). The EEI is defined as the amount of energy that has actually been used for the production of a package of energy-intensive commodities, divided by the amount of energy that would have been needed to produce the same package at the reference level of energy efficiency. An EEI of 1.0 thus reflects current reference levels for the specific energy requirements, given either by best available technologies or by best practice levels. Aggregated EEIs over the various subsectors in the energy-intensive industry are given in Table 2. It should be emphasized that these are preliminary figures, based on an incomplete coverage of countries and industrial subsectors within the regions.

Table 2. Aggregated Energy Efficiency Indices at the regional level (based on Groenenberg (2002). Regions with a low data coverage (<30%) are indicated with an asterisk

Region	Aggregated EEI	Region	Aggregated EEI	Region	Aggregated EEI
Western Europe	1.2	Middle East	1.6	Eastern Europe*	1.7
Japan	1.3	Africa*	1.6	USA	1.8
Canada*	1.3	South Asia	1.7	East Asia	1.9
Latin America	1.5	Oceania*	1.7	Former Soviet Union*	2.0
South East Asia	1.6				

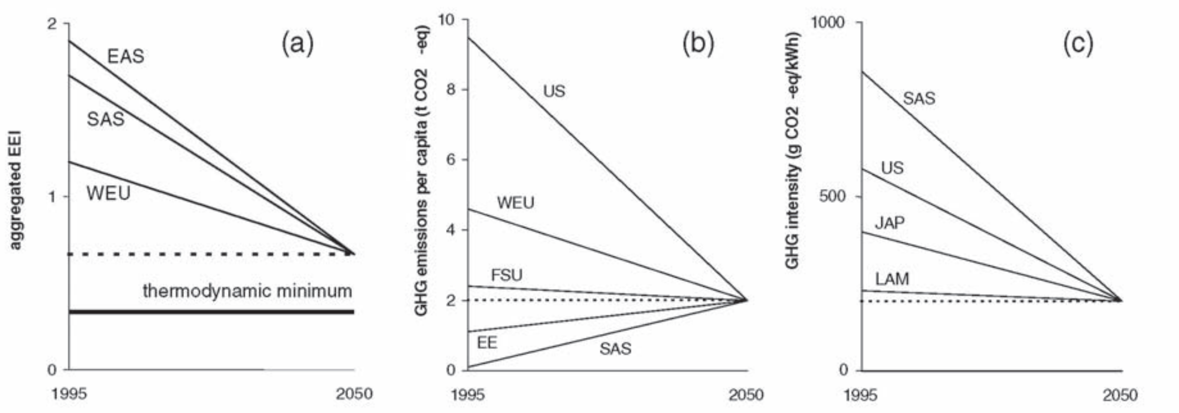


Figure 3. Illustrative examples of convergence by 2050 for all world regions (though only a selection is shown) of (a) Aggregated Energy Efficiency Indices (EEI) in the energy-intensive industry. An EEI of 1. 0 represents current reference levels for energy efficiency, e.g. based on best practice technologies; (b) per capita emissions in the domestic (RCTL) sectors; (c) greenhouse gas intensities of electricity production

From the slope of the linear convergence trajectories for the aggregated EEI (Figure 3a) we can derive by what proportion the energy use per unit of product is reduced on a year-to-year basis. Growth of total greenhouse gas emissions in this sector is then decreased by these reductions. In our calculations we assumed that the developing regions do not participate in the convergence of energy efficiencies before 2010. Until then we presupposed an autonomous efficiency improvement of 1% per year.

The convergence level for the EEI (0.67, with 0.75 and 0.5 as upper and lower values) was based on bottom-up studies of thermodynamic minimal energy requirements (Groenenberg, 2002). Assuming that roughly 15 years will be necessary for the development of the required new technologies, as suggested by Steger et al. (2002) and 30 years for the subsequent implementation, such a level could be realized half-way through this century. Lower and upper values for the feasible EEI by 2050 were estimated to be 0.5 and 0.75, respectively.

2.2. The domestic sectors (RCTL)

In our analysis, the domestic sectors comprise various sectors: not only the residential sector (households), but also the commercial sector, transportation, and light industry are included in this category, just as emissions related to combustion in agriculture and during the production of fossil fuels. Emissions in these sectors are assumed to be correlated to population size, since they are determined to a large extent by the number of people that live in dwellings, have a workplace, transport themselves, etc. The domestic (RCTL) sectors also comprise non-CO_2 emissions, which together make up 16% of the emissions (Figure 4). CH_4 and N_2O emissions relate to both combustion in this sector and to waste, while emissions of the fluorinated gases (HFCs, PFCs and SF_6) derive from a range of sources.

We need a population projection to underpin (non-binding) sectoral objectives in the domestic sectors. To this end we used the same projections as applied in section 2.1. These comprise a medium projection from the United Nations (UN, 1998) and high and low projections from Lutz *et al.* (1996). In our calculation of emission limitation objectives we assume that greenhouse gas emissions per capita will converge

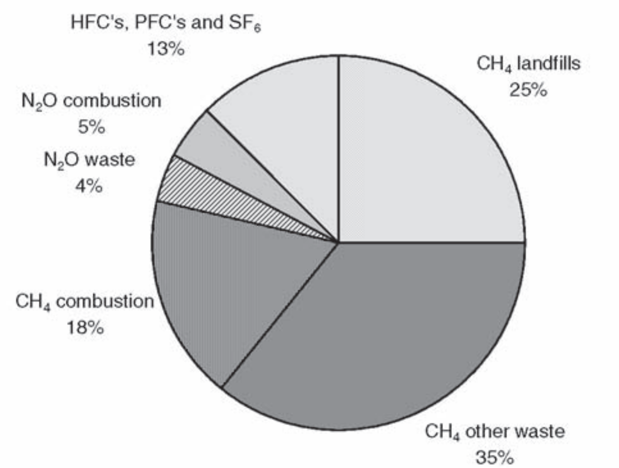


Figure 4. Contribution of various sources to the emission of 1995 non-CO_2 greenhouse gases in the domestic (RCTL) sectors. Non-CO_2 greenhouse gases make up 17% of total greenhouse gas emissions in the domestic sectors (based on EDGAR 3.2 database; Olivier *et al*. 2002)

linearly to the same level world-wide by 2050 (Figure 3b). We also assume that by the year 2050 all non-CO_2 emissions in the domestic sectors will have ceased entirely, since for the major sources there are considerable reduction potentials, which can be utilized as early as before 2010.[5] Since apparently non-CO_2 emissions can be abated entirely by 2050, the question remains what an achievable target would be for global per capita CO_2 emissions by the year 2050. This brings us to the question of how much energy is required to fulfil human needs. Several authors have tried to quantify these basic energy requirements. Goldemberg *et al*. (1988) calculated a per capita energy use figure for a hypothetical developing country 'for basic needs and much more'. The authors assume a combination of European activity levels in the 1970s with more efficient end-use technologies than those in common use in Europe by that time. However, the authors claimed that no extraordinary technologies requiring major technological breakthroughs were involved. With their calculation they aimed to illustrate that large improvements in living standards in developing countries are possible without an increase in energy use. Such improvement will result from the adoption of more efficient technologies, and from a shift from traditional, inefficiently used non-commercial fuels to modern energy carriers. They calculated a per capita energy use rate of slightly more than 1000 W per capita. Energy use in the energy-intensive industry makes up half of this figure. Table 3 lists the remaining activities, which can be attributed to the domestic (RCTL) sectors.

A view on basic energy needs from authors in the industrialized world comes from Imboden and Roggo Voegelin (2000), who assessed the minimum energy requirement for a typical family in Switzerland to be about 2000 W. Table 4 shows the breakdown of their figures.

The suggestions for per capita energy use set forth above are not meant to be prescriptive, but can be used to better underpin a long-term target for per capita final energy use in the domestic sectors in 2050. It seems reasonable to set such a target for fuel consumption somewhere in the range between 1000 and 2000 W. Present levels for per capita energy consumption and emissions in the domestic sectors are shown in Table 5.

In order to obtain a target for per capita emissions, we must consider what the composition of global primary energy supply in the domestic sectors by 2050 could be. Table 6 lists per capita emission levels that result from various assumptions concerning per capita energy use and fuel mix in the domestic sectors.

In their renewables-intensive global energy scenario Johansson *et al.* (1993) project a 40% contribution

Table 3. Activity levels and technological opportunities for a hypothetical developing country in a warm climate, excluding space heating (based on Goldemberg *et al.*, 1988). Amenities are comparable to those in Western Europe, Japan, Australia, New Zealand and South Africa in the 1970s but are provided with the best-available or advanced energy utilization technologies of the 1980s. Note that energy requirements for the energy-intensive industry and heating or cooling are excluded. The energy-use pattern presented here is meant to be illustrative, not prescriptive

Activity	Activity level	Technology, performance	Average rate of energy use (Watts per capita)		
			Power	Fuel	Total
Residential	4-persons/household (HH)[a]				
Cooking	Typical cooking level with LPG stoves	70% efficient gas stove		34	
Hot water	50 litres of hot water/ capita/day	heat pump water heater, of performance (heat output/electricity input) = 2.5	29		
Refrigeration	One 315 litre refrigerator-freezer/HH	Electrolux Refrigerator / Freezer, 475 kWh/year	14		
Lights	New Jersey (US) level of lighting	Compact Fluorescent Bulbs, using 18W but emitting as much light as a 75W bulb	4		
TV	1 colour TV/HH, 4 hours a day	75 Watt unit	3		
Washing machine	1/HH, 1 cycle a day	0.2 kWh/cycle	2		
Commercial	5.4 m^2 of floor space/capita,	Performance of 1981 most energy-efficient commercial building in Sweden (all uses, ex. space heating)	22		22
Transportation					
Cars	0.19 cars/capita 15,000 km/ car/year	Cummins/NASA Lewis Car at 3.0 l/100 km		107	
Intercity bus	1850 passenger (p)-km/capita	¾ energy intensity in 1975		26	
Passenger train	3175 p-km/capita	¾ energy intensity in 1975	5	32	
Urban mass transit	520 p-km/capita	¾ energy intensity in 1975	2	8	
Air travel	345 p-km/capita	½ US energy intensity in 1980		21	
Truck freight	1495 ton (t)-km/capita	0.67 MJ/ton (t)-km (1/3 below mid 1980s performance in Sweden)		32	
Rail freight	814 t-km/capita	Electric rail at 0.18 MJ/t-km (Swedish level)	5		
Water freight	½ OECD Europe avg., 1978	60% of OECD energy intensity		50	
Agriculture	WE/JANZ[b] average, 1975	¾ of WE/JANZ energy intensity	4	41	45
Mining, Construction	WE/JANZ[b] average, 1975	¾ of WE/JANZ energy intensity	–	59	59
TOTAL excl. heating/cooling					500

[a] Though a four-person household is the starting point, energy use is presented on a per capita basis.
[b] Western Europe, Japan, Australia, New Zealand.

Table 4. Activity levels and annual per capita energy use for a four-person Swiss family in a 2000 W society (Imboden and Roggo Voegelin, 2002)

	Activity level	Final/primary energy use (W)
Residential and commercial	Floorspace 75 m^2, 150 MJ/m^2/year Electricity	360/450
	1500 kWh/year	170/210
Transportation, automobile	3000 km/cap/year, 3 litre per 100 km	140/140
Public transport	3000 km/cap/year, 0.3 kWh/km	100/100
Air travel	2000 km/cap/year, 0.8 kWh/year	180/230
Food and consumption foods		400/400
Subtotal		1580
Infrastructure	20% energy use in subtotal	340
TOTAL		1920

Table 5. Total final energy use per capita (W; fuels only) and greenhouse gas emissions per capita (t CO_2-eq) in the domestic sectors[a] in 1995 (based on IEA, 1997; Olivier, 2002)

Region	Energy use rate (W/cap)[b]	GHG emissions (t CO_2-eq/cap)	Region	Energy use rate (/W/cap)	GHG emissions (t CO_2-eq/cap)
USA	4900	10.3	Eastern Europe	900	2.7
Canada	4500	10.0	Latin America	600	1.7
Former Soviet Union	2200	4.1	South East Asia	300	0.8
Western Europe	2100	4.6	East China	300	1.0
Oceania	2000	4.5	South Asia	100	0.5
Japan	1800	4.6	Africa	100	0.6
Middle East	1100	2.6	*World*	*800*	*2.0*

[a] Calculated as Total Final Consumption energy use in the iron and steel, chemical, non-ferrous metals, non-metallic minerals and paper and board industries non-energy use in industry and transformation.
[b] Rounded to multiples of 100.

Table 6. Possible objectives for global per capita energy use, composition of global primary energy supply and per capita emissions in the domestic sectors for the year 2050[a]

Per capita energy use rate (W)	Renewables	Natural gas	Oil	Coal	Per capita emissions (t CO_2)
1000					1.4
1500	40%	20%	20%	20%	2.1
2000					2.8
1000					1.6
1500	30%	30%	20%	20%	2.3
2000					3.1

[a] Excluding power generation and the energy-intensive industry.

of renewables for purposes other than electricity generation, and more or less equal proportions of coal, oil and natural gas in the remaining 60%. Carbon-free energy sources in the coming decades may also result from fossil fuel based energy from which emitted CO_2 has been sequestrated. Combined with a global per capita energy use of 1500 W, this would mean per capita emissions of 2.1 t CO_2 annually. For our base case calculations we will take a long-term target of 2.0 t CO_2 per capita in 2050 for emissions in the domestic sectors. The lower and upper values for per capita emissions in the domestic sectors that follow from these are 1.5 and 3.0 t CO_2, respectively. We stress that the described energy use patterns were not put forward in order to be imposed upon anyone. Note that a minority of the global population both in industrialized countries and in the upper class of developing countries today have levels of per capita energy use that are already well above the levels for 'basic needs and much more' used in the present study. Whether energy-related emissions of this well-off part of the population could be reduced sufficiently might depend on their use of low or zero carbon energy.

2.3. The power-producing sector

In our analysis we distinguish the power-producing sector[6] because specific CO_2 emissions from power production vary to a large extent across countries, due to large differences in the role of nuclear power and renewables and in the fuel mix in fossil-fuel-fired power plants. The potential for cutting CO_2 emissions in this sector differs accordingly. Therefore fuel mix in power generation is an important national circumstance that has to be taken into account in a differentiation of commitments. In order to estimate growth in the power-producing sector we assumed that this growth is determined by the growth of the energy-intensive industry on the one hand and by the growth in the domestic sectors on the other. We projected future growth in power production as the weighted sum of growth in total final energy use in the energy-intensive industry and in the domestic sectors. Per capita final energy use in the domestic sectors was assumed to converge to a level between 1000 and 2000 W. Evolution to a low-carbon economy is a prerequisite for the stabilization of atmospheric greenhouse gas concentrations. Therefore we start from the assumption that world-wide greenhouse gas intensities of the power produced will converge linearly to the same low level by the year 2050 (Figure 3c). Developing regions participate in the convergence as from 2010. Until then, no mitigation efforts are presupposed in this sector.

Present levels of greenhouse gas intensities of electricity production are listed in Table 7. In order to set a reasonable long-term target for the greenhouse gas intensity of electricity throughout the world, one needs to estimate what the composition of global primary energy supply will be by 2050. In their renewables-intensive scenario Johansson *et al*. (1993) suggested a 60% share of renewables in electricity generation by the year 2050.

If we assume a 60% share of renewables and equal shares of natural gas-, oil- and coal-based capacity,

Table 7. 1995 greenhouse gas intensities from electricity (IEA, 1997, Olivier, 2002)

Region	GHG intensity (g CO_2-eq/kWh)	Region	GHG intensity (g CO_2-eq/kWh)	Region	GHG intensity (g CO_2-eq/kWh)
Canada	190	Africa	590	Eastern Europe	660
Latin America	230	South East Asia	610	Former Soviet Union	700
Western Europe	390	Middle East	640	East Asia	790
Japan	400	Oceania	660	South Asia	860
USA	580			*World*	*640*

Table 8. Possible compositions of primary energy supply in power generation for the year 2050 and accompanying CO_2 intensity of electricity. For gas-, oil- and coal-based capacity, conversion efficiencies of 65%, 50% and 50%, respectively, were assumed.[a]

Composition primary energy supply in power generation (%)				Greenhouse gas intensity of electricity (g/kWh)
Renewables	Gas	Oil	Coal	
60	40	0	0	124
60	13	13	13	203
50	17	17	17	253
40	20	20	20	304

[a] These assumptions seem justified considering present performances. At present the state-of-the-art conversion efficiency for natural gas-fired power generation is 58% and approaches 60% on a lower heating value basis (Smith, 1999). For solid and liquid fuels these values are now well over 45% (Anonymous, 1995). We presuppose that further improvements by 2050 may improve efficiencies by 5%.

then the CO_2-intensity of power will be just over 200 g CO_2-eq/kWh, which will be the convergence level for our base case calculations. Lower and upper values for the CO_2 intensity follow from Table 8; these are equal to 125 and 300 g CO_2-eq/kWh.

2.4. Fossil fuel production

Methane emissions from coal mining and from oil and gas production and distribution make up only a very small part of global greenhouse gas emissions (see Figure 1). For both there are major reduction options available for 2010 (IEA-GHG, 1999; Hendriks *et al*., 2001b). It is technologically feasible to reduce methane emissions from fossil fuel production by over 90%. Although the economic potential at present is limited, the time horizon of our calculations (2050) justifies the assumption that the technological potential will eventually be exploited to a large extent. In all our calculations we therefore let relative methane emissions (i.e. methane emissions divided by fossil fuel related CO_2 emissions) decline linearly to a level of 90% below the 1995 ratio. Please note that CO_2 emissions from energy *used* during the production of fossil fuels have been included in the domestic (RCTL) sectors.

2.5. Agriculture

Agriculture is responsible for considerable amounts of methane and nitrous oxide emissions. Methane is emitted from enteric fermentation, annual manure, and from irrigated rice fields. Nitrous oxide is emitted from manure in store and from manure deposited on soil by animals. Major sources of nitrous oxide are arable land following the application of fertilizers (both manure and artificial), the mineralization of organic soils and crop residues, and indirect nitrogen losses after leaching, runoff or atmospheric deposition (Kroeze and Mosier, 2000). Together these emissions make up 16% of global greenhouse gas emissions.

Future CH_4 and N_2O emissions will be the result of activity growth (i.e. food production) on the one hand and emission reduction options on the other. Table 9 summarizes, for each of the agricultural sources of CH_4 and N_2O, the 1995 emissions, projected growth by 2020 and perceived reduction opportunities (for further details see Groenenberg, 2002).

Table 9 shows that the growth of baseline CH_4 and N_2O emissions from agriculture and the reduction options for these gases will partly balance each other. Therefore, we will assume that methane and nitrous oxide emissions from agriculture in our base case calculations will stabilize. We will test the

Table 9. 1995 global CH_4 and N_2O emissions from agriculture (Olivier, 2002), growth projections by 2020 and perceived reduction opportunities

	1995* ($GtCO_2$-eq)	2020 Growth projection	Technical reduction potential per unit of activity
Methane			
Enteric fermentation	1.8 ±50%	0–20%[a]	15–70% in developing countries 50–100% in industrialized world[b]
Manure in store	0.18 ±50%	50–80%[c]	40% in developing countries 75% in industrialized world[d]
Irrigated Rice	0.7 ±100%	30–40%[e]	40%[f]
Nitrous oxide			
Arable land[g]	2.9 ±100%	20–30%[h]	20%[i]
Manure in store	0.18 ±50%	50–80%[c]	0%[d]

[a] Projections concern number of animals (IMAGE-team, 2001).

[b] (de Jager *et al*., 2001). Economic potentials in an implementation scenario for 2020 are roughly 0–20% for the developing world and 35–65% for the industrialized world.

[c] Projections concern global meat production (IMAGE-team, 2001).

[d] (de Jager *et al*., 2001). Economic potentials in an implementation scenario for 2020 are roughly 10% for the developing world and 70% for the industrialized world.

[e] (IMAGE-team, 2001).

[f] (Mosier *et al*., 1998; IEA-GHG, 1999).

[g] Artificial and organic fertilizer use, manure deposited during grazing, biological N fixation, crop residues and indirect emissions after NH_3 deposition and N leaching and run-off.

[h] Based on Fischer *et al*. (2002), who state that arable land may potentially be expanded by one-third. However, since it is uncertain if this potential can and will be exploited fully, we project growth of arable land of 20–30% by 2020.

[i] (Mosier *et al*.,1998).

possible implications of disappointing mitigation performances in agriculture in our calculations, by assuming that agricultural emissions of methane and nitrous oxide keep up with the growth of the global population, which in the medium scenario will be 35% by 2020.

As in the sector of fossil fuel production, CO_2 emissions from the energy used in the agricultural sector have been included in the domestic sectors.

2.6. Deforestation

Global emissions from land-use change are substantial. Tropical deforestation and degradation due to overexploitation or natural disasters is a major contributor to these emissions, while forest area in developed countries has stabilized and is increasing slightly overall (FAO, 2002).

The difficulties in determining feasible deforestation rates made us decide to exclude emissions from deforestation from most of our calculations of emission objectives. However, if we wish to compare total global allowed emissions resulting from our calculations to an emission profile leading to atmospheric stabilization of greenhouse gas concentrations (see section 4), we need to make an assumption about future emissions from deforestation. To this end we introduce a linear convergence of per capita emissions to zero by the year 2050 as a normative criterion in the calculation of total emission allowances. The rationale for this per capita basis is that although efforts are focused on halting deforestation, particularly in the developing world, the reality is that deforestation is likely to continue due to commercial interests

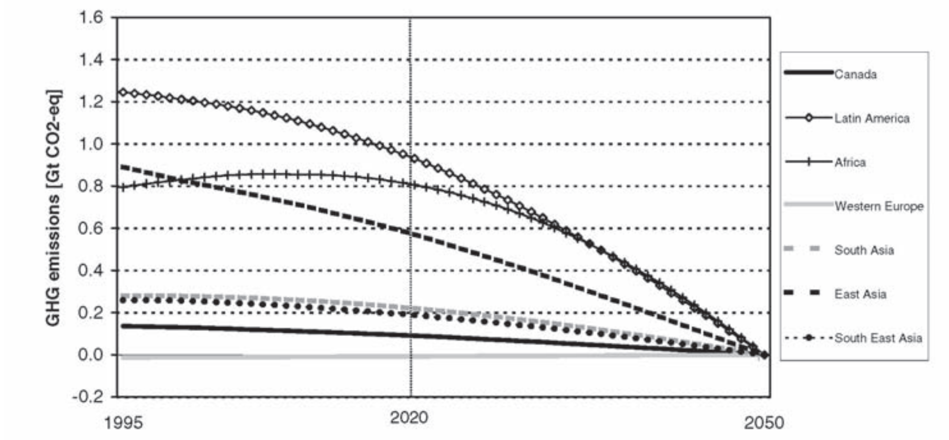


Figure 5. Convergence of per capita emissions from deforestation to zero in 2050

and by pressures related to population growth in some developing countries in the coming decades. Convergence of emissions on a per capita basis allows for more emissions in the coming decades than convergence of absolute emissions from deforestation. The resulting trajectories for emissions from deforestation are depicted in Figure 5. If we were also to include the global cost-effective mitigation potential through afforestation and reforestation in the calculations, mankind could increase globally allowed emissions until 2020 by 2–3%.[7]

3. Resulting emission objectives

Table 10 shows parameter settings in the base case and the resulting cumulative emissions and emission objectives for the different world regions as a percentage of 1995 emissions. Two sets of emission objectives are listed: one set represents the change in total greenhouse gas emissions by 2020, whereas the other set excludes greenhouse gas emissions from deforestation, both for 1995 and for 2020. The inclusion of deforestation emissions mainly affects regions with currently high deforestation rates in Latin America, Africa and developing Asia.

The stringency of the calculated emission reduction objectives can be understood if one looks into the sectoral objectives. Note that the sectoral objectives are only a means to underpin the total objective for a region. Sectoral objectives for the energy-using sectors are listed in Table 11.

For the energy-intensive industry, Table 11 lists the growth factors for production by the year 2020 and the present Energy Efficiency Index; together these explain the established sectoral objectives. The most stringent sectoral objectives in this sector are for industrialized regions, excluding the Former Soviet Union. Projected growth in these industrialized regions is low. In addition, energy efficiencies in Oceania and Eastern Europe are relatively poor. The latter is also true for the USA, but here projected growth is somewhat higher, following higher population projections. For Canada the same growth is anticipated as for the USA, but according to our information the USA has poorer efficiency performance in this sector, resulting in a lower emission growth allowance. Emission growth in the energy-intensive industry is also anticipated in the developing world, with projected production growth factors ranging from 1.8 to 5.4 and Energy Efficiency Indices between 1.5 and 1.9. The Former Soviet Union is also allowed to grow in this sector. The projected doubling of production growth in the 1995–2020 period can

Table 10. Base case parameter settings and emission limitation objectives for 2020 (compared with 1995 levels) calculated with the Global Triptych approach. Growth of population and physical production in the energy-intensive industry are medium, while emissions from fossil fuel production decrease by 40% in 2020. Emissions from agriculture are supposed to stabilize. Deforestation emissions per capita converge to zero in 2050

Long-term convergence targets 2050		
Energy-intensive industry: Energy Efficiency Index	0.67	
Domestic sectors: Emissions per capita	2.0 t CO_2-eq	
Power generation: Greenhouse gas intensity of electricity	200 g CO_2-eq/kWh	
Emission limitation objectives compared to 1995	**including deforestation**	**excluding deforestation**
Canada	-18%	-14%
USA	-27%	-27%
Latin America	10%	29%
Africa	95%	140%
Western Europe	-19%	-19%
Eastern Europe	-16%	-16%
Former Soviet Union	-23%	-21%
Middle East	33%	34%
South Asia	187%	213%
East Asia	36%	47%
South East Asia	59%	77%
Oceania	-12%	-14%
Japan	-21%	-21%
World	*19%*	*24%*

77% , 206% , 151% and 128% for Northern, Western, Eastern and Southern Africa respectively; region definitions according to IMAGE-team (2001).

Table 11. Sectoral breakdown of the emission objectives for the year 2020 (compared with 1995 levels) for three sectors in the base case, established with the Global Triptych approach

Energy-intensive industry				Domestic sectors				Power generation				
	Average growth projection 2020	1995 Energy Efficiency Index	Sectoral objective		Medium population growth 2020	1995 emissions (t CO_2-eq/cap)	Sectoral objective		Energy-intensive industry, TFC[a]	Domestic sectors, TFC[a]	1995 GHG intensity (g CO_2-eq/kWh)	Sectoral objective
Canada	1.4	1.3	9%	Canada	1.22	10.0	-22%	Canada	9%	-27%	190	-16%
USA	1.4	1.8	1%	USA	1.22	10.3	-23%	USA	1%	-28%	580	-49%
Latin America	1.8	1.5	38%	Latin America	1.37	1.7	50%	Latin America	38%	132%	230	95%
Africa	4.9	1.6	256%	Africa	1.86	0.6	263%	Africa	256%	1213%	590	275%
Western Europe	1.2	1.2	-2%	Western Europe	1.05	4.6	-22%	Western Europe	-2%	-15%	390	-32%
Eastern Europe	1.3	1.7	-5%	Eastern Europe	0.99	2.7	-13%	Eastern Europe	-5%	20%	660	-23%
FSU	2.1	2.0	48%	FSU	1.02	4.1	-22%	FSU	48%	-16%	700	-37%
Middle East	2.2	1.6	64%	Middle East	1.60	2.6	43%	Middle East	64%	77%	640	45%
South Asia	5.4	1.7	302%	South Asia	1.45	0.5	260%	South Asia	302%	1023%	860	600%
East Asia	2.0	1.9	48%	East Asia	1.18	1.0	68%	East Asia	48%	224%	790	83%
South East Asia	2.5	1.6	88%	South East Asia	1.33	0.8	116%	South East Asia	88%	358%	610	215%
Oceania	1.3	1.7	-4%	Oceania	1.14	4.5	-15%	Oceania	-4%	-7%	660	-36%
Japan	1.2	1.3	-5%	Japan	1.03	4.6	-23%	Japan	-5%	-11%	400	-30%

[a] Total final energy consumption.

be explained partly because the Former Soviet Union has to make up for the collapse in production in the early 1990s. Physical production levels for steel, petrochemicals, cement and refined petroleum products were halved in these years (UN, 1998). It will first need to make up for this drop in production levels before the levels exceed the production levels reached in the late 1980s.

Adjacent to the sectoral objectives for the domestic sectors are the growth factors for population size by the year 2020 and the present level of per capita greenhouse gas emissions. The larger part of the industrialized world is assigned a sectoral objective somewhat below -20%. Population projections for Japan, the Former Soviet Union and Western Europe are on the low side. Domestic per capita emissions in these regions are between 4 and 4.5 t CO_2-eq, which is more than twice as high as the long-term target for per capita emissions in the base case. Canada and the USA, on the other hand, currently have even higher domestic per capita emissions, but this is countered by the relatively larger population projections. Eastern Europe and Oceania are assigned sectoral objectives for the domestic sectors that are almost equally stringent. Although Oceania has higher domestic per capita emissions, population growth until 2020 will be much larger. The developing regions are again assigned large sectoral objectives, as a result of present low per capita emissions in the domestic sectors and projected large population growth. Sectoral objectives in the power-producing sectors follow from emissions in the energy-intensive industry and the domestic sectors on the one hand and from current greenhouse gas intensities of power on the other. All industrialized regions are supposed to reduce their emissions in this sector following trends of decreasing energy use in the other sectors and the reduction of greenhouse gas intensity of electricity production. Notwithstanding the presumed reduction in the greenhouse gas intensity, developing countries are allowed room for emission growth in power production. The high overall allowances for the developing world may not seem in line with the currently high GHG intensities in the power-producing sector. This can be explained since activity growth in this sector is linked to growth in the domestic (RCTL) sectors and the energy-intensive industry. Therefore the high sectoral allowances for power generation are mainly a result of the projected large population growth in these regions.

We tested the implications of various changes in settings of the long-term targets (Table 12). Choosing the upper values for any of the long-term targets while keeping the others at their base case value affects global emissions in all cases. The effect is largest if the target for ‘domestic’ per capita emissions is increased.

Furthermore we performed a number of sensitivity analyses to test the consequences of alternative growth assumptions (Table 13). These concern the consequences of lower and higher growth of production in the energy-intensive industry and of the population. We made also several crosswise combinations of low and high projections for the population and growth of the energy-intensive industry. Results are listed in Table 14. The most plausible combination of growth assumptions will vary over the world regions. While high population growth may lead to higher industrial output levels in some (richer) regions, it may lead to increased poverty, a reduced economic growth and lower output levels in poorer regions. Note that alternative growth assumptions do not affect the emission limitation objectives as much as alternative long-term targets.

For agricultural emissions of methane and nitrous oxide there is a range of reduction opportunities (see section 2.5). However, it may not be feasible to implement these reductions, at least not within two decades, particularly in parts of the world where peasant farmers are numerous, which are not easily accessible and are underdeveloped. The fourth column in Table 13 shows the implications of the assumption that agricultural emissions until 2020 will keep pace with population growth. Such an assumption would affect most objectives only slightly. Objectives for Oceania and Latin America would be relaxed most.

Table 12. Sensitivity analyses for total 2020 objectives (compared with 1995 levels; excluding emissions from deforestation) resulting from the Global Triptych for various settings of the long-term targets. Growth of population and physical production in the energy-intensive industry is medium, while emissions from agriculture are supposed to stabilize. The first list represents the base case

Long-term convergence targets 2050							
Energy Efficiency Index	0.67	0.50	0.75	0.67	0.67	0.67	0.67
Domestic emissions per capita (t CO_2-eq)	2.0	2.0	2.0	2.0	2.0	1.5	3.0
GHG intensity of electricity (g CO_2-eq/kWh)	200	200	200	125	300	200	200
Emission limitation objectives (excluding deforestation)							
Canada	-14%	-16%	-13%	-17%	-11%	-16%	-10%
USA	-27%	-28%	-27%	-29%	-25%	-29%	-23%
Latin America	29%	28%	30%	28%	31%	20%	46%
Africa	140%	139%	141%	138%	144%	109%	208%
Western Europe	-19%	-21%	-18%	-21%	-16%	-22%	-12%
Eastern Europe	-16%	-18%	-15%	-18%	-13%	-21%	-6%
Former Soviet Union	-21%	-22%	-21%	-23%	-19%	-25%	-14%
Middle East	34%	33%	35%	33%	36%	24%	54%
South Asia	213%	210%	214%	209%	218%	170%	296%
East Asia	47%	45%	48%	46%	49%	36%	68%
South East Asia	77%	76%	78%	76%	79%	58%	115%
Oceania	-14%	-15%	-14%	-15%	-13%	-17%	-9%
Japan	-21%	-23%	-20%	-23%	-18%	-25%	-14%
World	24%	23%	25%	23%	27%	14%	44%

Table 13. Sensitivity analyses for 2020 objectives (above 1995 levels; excluding emissions from deforestation) using alternative long-term convergence targets and alternative growth assumptions

Long-term convergence targets 2050						
Energy Efficiency Index	0.67				0.75	
Domestic emissions per capita (t CO_2-eq)	2.0				250	
GHG intensity of electricity (g CO_2-eq/kWh)	200				300	
Growth						
Population	Low	Medium	High	Medium	Medium	High
Energy-intensive industry	Low	Medium	High	Medium	Medium	High
Agricultural emissions	Constant	Constant	Constant	As population	Constant	Constant
Emission limitation objectives (excluding deforestation)						
Canada	-14%	-14%	-12%	-11%	-5%	-3%
USA	-27%	-27%	-25%	-25%	-21%	-18%
Latin America	28%	29%	40%	43%	49%	63%
Africa	130%	140%	145%	155%	214%	219%
Western Europe	-18%	-19%	-15%	-15%	-8%	-4%
Eastern Europe	-16%	-16%	-13%	-13%	-2%	2%
Former Soviet Union	-22%	-21%	-13%	-18%	-11%	-1%
Middle East	36%	34%	52%	39%	57%	79%
South Asia	198%	213%	247%	228%	304%	349%
East Asia	39%	47%	68%	54%	71%	97%
South East Asia	67%	77%	95%	88%	118%	141%
Oceania	-14%	-14%	-12%	-1%	-7%	-4%
Japan	-20%	-21%	-17%	-20%	-9%	-4%
World	21%	24%	35%	31%	47%	61%

Table 14. Sensitivity analyses for 2020 objectives (above 1995 levels; excluding emissions from deforestation) using alternative growth assumptions in the Global Triptych approach, with long-term targets in 2050 equal to those in the base case (Energy Efficiency Index 0.67, greenhouse gas intensity of power 200 g CO_2-eq/kWh, domestic emissions per capita 2.0 t CO_2-eq). The middle list represents the base case

Growth					
Population	Low	Low	Medium	High	High
Energy-intensive industry	Low	High	Medium	Low	High
Emission limitation objectives (excluding deforestation)					
Canada	-14%	-14%	-14%	-12%	-12%
USA	-27%	-27%	-27%	-25%	-25%
Latin America	28%	29%	29%	38%	40%
Africa	130%	132%	140%	142%	145%
Western Europe	-18%	-17%	-19%	-16%	-15%
Eastern Europe	-16%	-15%	-16%	-13%	-13%
Former Soviet Union	-22%	-20%	-21%	-16%	-13%
Middle East	36%	38%	34%	49%	52%
South Asia	198%	206%	213%	230%	247%
East Asia	39%	44%	47%	58%	68%
South East Asia	67%	71%	77%	87%	95%
Oceania	-14%	-14%	-14%	-12%	-12%
Japan	-20%	-19%	-21%	-18%	-17%
World	21%	23%	24%	31%	35%

We also performed a set of calculations in which we set all long-term targets equal to their upper values. The resulting emission objectives are listed in the two rightmost columns in Table 13. Obviously this results in higher global emissions. Under high growth allowances global emissions would be even higher.

4. Stabilization of greenhouse gas concentrations

If it is to serve as a decision-support tool the Global Triptych approach must be in agreement with the ultimate objective of international climate policy, phrased as the stabilization of atmospheric greenhouse gas concentrations. Up until now, no target has been quantified for the concentrations levels at which stabilization should take place. A political decision on this would require insight into the implications of stabilization at different levels. Indications in the literature are that stabilization at 450 ppm would result in an increase of less than 2 ºC within a century and a little over 2 ºC in the long term, whereas projected results of a 550 ppm stabilization level are slightly more than 2 ºC by 2100 and almost 3 ºC ultimately (Cubasch *et al*., 2001). Based on literature studies Rijsberman and Swart (1990) advocated 2 ºC as an absolute limit for global temperature increase. An increase less than 0.1 ºC per decade may allow ecosystems sufficient time to adapt (Krause *et al*., 1989). In addition, total temperature increase should be limited to 1.0 ºC relative to pre-industrial global temperature to avoid unpredictable and non-linear ecological responses, which could lead to extensive ecosystem damage. Furthermore, Arnell *et al*. (2002) assessed the global-scale implications of stabilizing atmospheric CO_2 concentrations at 750 ppm (by 2250) and 550 ppm (by 2150). They estimated impacts on natural vegetation, water resources, coastal flood risk and wetland loss, crop yield and food security, and malaria. They found that achieving CO_2 stabilization at either 750 or 500 ppm *delays* some of the adverse consequences of climate change, although the effects vary between the impact sectors and also geographically. Stabilization at 550 ppm also appears to *prevent* some very significant adverse impacts in the long term, particularly the loss of large areas of tropical forest and severe increases in water scarcity. The results indicate that stabilization at relatively low levels would have an appreciable effect in reducing several impacts of climate change.

Note that the European Union has adopted a maximum 2 ºC increase over pre-industrial levels as a guiding long-term objective, alongside an atmospheric CO_2 concentration of below 550 ppm (European Parliament, 2001).

In order to examine how the 2020 distribution of commitments fits into a stabilization of greenhouse gas concentrations at low levels, we assume that Global Triptych is not only applied until the year 2020, but also over the period thereafter. We have compared cumulative allowed emissions in the 1995–2050 period to cumulative greenhouse gas emissions according to profiles for stabilization at low atmospheric concentrations. The course of global greenhouse gas emissions until 2050 according to the Global Triptych approach is shown in Figure 6. The picture also depicts possible emission profiles for stabilizing atmospheric greenhouse gases at 550 ppm CO_2-eq (about 450 ppm CO_2) and 650 ppm CO_2-eq (about 550 ppm CO_2) by the end of this century, constructed by Eickhout *et al*. (2002). We found that cumulative emissions until 2050 in the base case exceed cumulative emissions according to the 450/550 profile by 7%.[8] Base case emissions are 12% lower than cumulative emissions according to the 550/650 profile.

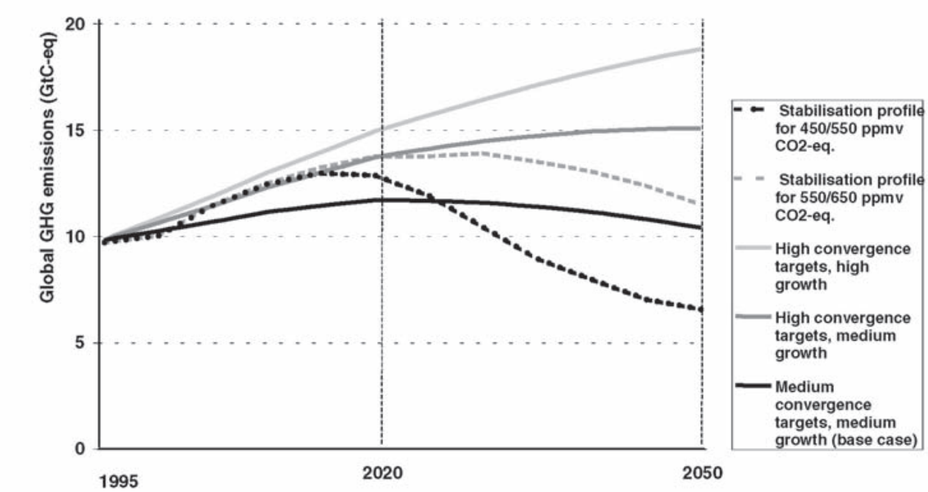


Figure 6. Global greenhouse gas emissions according to the Global Triptych approach including emissions from deforestation. The cases represented correspond to the base case and the cases in the two rightmost columns in Table 13. Stabilization profiles are based on Eickhout *et al*. (2002)

5. Agreement with the basic principles of the Climate Convention

We will now discuss to what extent the approach just presented agrees with the basic principles of the Climate Convention. One of the basic principles in the Convention requires that full consideration be given to the specific needs and special circumstances of developing country Parties (Article 3.2). This principle partly overlaps with the principle laid down in Article 3.1, which refers to the notion of equity and ‘common but differentiated … capabilities’.[9]

According to these principles, basic energy needs must be secured in order to provide for a decent standard of living. The Global Triptych approach starts from a per capita energy consumption of 1500 W in the domestic sectors. Tables 3 and 4 indicate that this may well be sufficient to fulfil basic needs. Furthermore the developing countries have insisted and will continue to insist that they should have the right to realize their own social and economic development objectives. We gave special attention to these development claims, not only by taking into account basic needs for energy consumption in the domestic sectors, but also by using a well-founded projection for physical production in the energy-intensive industry. This projection was based on consistent population and economic projections and is the average projection over a range of future world images.

Another principle is the cost-effectiveness of climate change mitigation. Article 3.3 of the Convention states that 'policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost'. It may be perceived as equitable that a Party that has a large portfolio of low-cost reduction options at its disposal is assigned a more stringent reduction objective. Several models have therefore taken cost-effectiveness as an explicit starting-point. They equalize marginal mitigation costs over the participating Parties (see e.g. Babiker *et al*., 2001; ETSAP, 2001). However, the architecture of the Kyoto Protocol itself has reduced the relevance of equalizing mitigation costs fully. The Kyoto mechanisms enable Parties to realize emission reductions in a cost-effective manner regardless of the costs of domestic action. Nevertheless, there is still good reason for aspiring to a certain degree of cost-effectiveness in a differentiation scheme. Incorporating the ability to reduce greenhouse gas emissions domestically is a way of reflecting a certain degree of cost-effectiveness in a differentiation scheme.

Finally, climate change mitigation measures and sustainable development need to be harmonized (Article 3.4). Local circumstances and development objectives must be observed while technologies that are more energy-efficient or contribute to a less carbon-intensive energy supply are being implemented. The technical part of such sustainable development is reflected in the convergence trajectories for energy efficiency in the energy-intensive industry and greenhouse gas intensity of electricity production.[10]

6. Conclusions

In this article we have explored a new approach for the differentiation of commitments by world regions. We attempted to assess its implications for emission limitation objectives and globally allowed emissions, starting from bottom-up information on emission reduction opportunities. From our analysis a number of conclusions can be drawn.

We demonstrated that it is possible to accommodate within one scheme important basic principles and the ultimate objective of the Climate Convention, which is to stabilize atmospheric greenhouse gas concentrations. To start with, the approach considers various interpretations of the principle of equity. For the domestic (RCTL) sectors we interpreted equity as 'basic energy needs'. For the energy-intensive industry and power generation we took the equity into account by considering regional differences in the 'ability to reduce', i.e. in technological reduction opportunities. Second, we considered the needs and circumstances of developing countries, in particular their need to expand and improve basic infrastructure, and the desire to attain western welfare levels. We gave special attention to these development claims, not only by taking into account basic needs for energy use in the domestic sectors, but also by using a well-founded projection for physical production in the energy-intensive industry. Third, the Global Triptych approach considers cost-effectiveness. While costs have not been equalized fully on a country-by-country basis, cost-effectiveness has been taken into account implicitly by including present energy efficiency levels, greenhouse gas intensities of electricity, and opportunities for reducing non-CO_2 emissions. Fourth, the approach gives consideration to the quest for sustainable development, which has been quantified as growth combined with technological improvement, although utmost care is needed, particularly in developing countries, to actually realize such technological improvement in accordance with local circumstances.

The reflection of four out of the five basic principles was possible particularly because bottom-up information has been included on energy efficiency in the energy-intensive industry, greenhouse gas intensity of electricity, domestic per capita energy use and production levels of energy-intensive commodities in recent times.

Notwithstanding value-laden choices in the setting of the parameters within the Global Triptych approach and uncertainties as to how the future may evolve, the ranking of world regions in the established differentiation of emission objectives remains roughly the same. Emission limitation objectives established with the Global Triptych approach range from roughly –30% to more than 200% compared with 1995 emissions. The objective turned out to be most stringent for the USA, the Former Soviet Union, and Japan. These are followed by reduction objectives for Eastern and Western Europe, Oceania and Canada. Latin America, the Middle East and the China region are assigned growth objectives. Highest growth objectives are for South East Asia, Africa, and the India region.

Stabilizing atmospheric concentrations at relatively low levels will require considerable emission reductions that probably cannot be attained with low-cost reduction options only. In this study we took atmospheric CO_2 concentrations of 450 ppm and greenhouse concentrations of 550 ppm CO_2-eq as a safe stabilization level. This level is associated with a maximum allowable temperature increase of 2 ºC. High growth of the population and the energy-intensive industry may lead to exceeding this level. Disappointing reductions in agricultural emissions of methane and nitrous oxide emissions may further contribute to this. This will happen even if considerable reduction efforts are made in all energy-using sectors.

Calculations of emission limitation objectives will gain in importance if international agreement can be reached on desirable levels for stabilizing atmospheric greenhouse gas concentrations. To that end, further insight is needed into the global and regional impacts associated with different atmospheric stabilization levels.

We found that economic growth assumptions as a major indicator of activity levels can be eliminated from differentiation calculations; high world-wide economic growth assumptions do not sufficiently take into account structural changes to less energy-intensive sectors or the fast-ageing populations in all world regions except Africa. Instead, future emissions growth can be related to present emission levels, population growth (and ageing) or growth in the production of energy-intensive commodities. This reduces the variability in possible growth allowances of energy related and other greenhouse gas emitting sources.

Finally, and probably most important, it would be desirable to gather responses to the Global Triptych approach from the international community, both from policy-makers and academia. Elements in the approach that may be responded to comprise the notion of long-term sustainability targets in the energy-consuming sectors, the anticipated development trajectories in the energy-intensive industry, the trade-off between activity growth and reduction opportunities in agriculture, and the role of emissions from deforestation. Reactions may also regard the perceived degree of fairness incorporated in the approach, the cost-effectiveness of the established differentiation, or its environmental effectiveness. In addition, it would be useful to discuss the quantitative outcome of our study in close connection with the timing of new commitments. Supporting mechanisms, either financial or legal, which may help Parties to comply with their emission objectives, need close consideration as well. In our view, this study includes sufficient elements to help stimulate the debate on the differentiation of future commitments under the Climate Convention.

Acknowledgements

We would like to thank Michel den Elzen for providing useful suggestions for this study.

Notes

1 We acknowledge that mitigation commitments can take many forms. Nevertheless, in this article we will focus on quantitative emission limitation objectives only.
2 A triptych is normally a work of art in three sections.
3 Iron and steel, chemicals, pulp and paper, non-metallic minerals, non-ferrous metals and the energy transformation sector, including petroleum refining, the manufacture of solid fuels, coal mining, oil and gas extraction and any energy transformation other than electricity production.
4 Time horizons studied by Groenenberg (2002) are as follows: crude steel: 1985–1994; cement 1986–1995; aluminium: 1987–1995; paper and board: 1980–1995; petrochemicals: 1987–1995; refining industry: 1980–1995.
5 CH_4 emissions from landfill sites can be reduced almost entirely at a cost of less than €20/t CO_2-eq and the reduction potentials for CH_4 emissions from aerobic and anaerobic wastewater treatment are as much as 100% (Hendriks *et al.*, 2001a). Combustion-related CH_4 emissions will decrease as the proportion of renewable energy in the domestic sectors increases. As for the halogenated gases, it is possible to reduce 50% of the emissions at costs of less than €20/t CO_2-eq and roughly 90% at costs of less than €50/t CO_2-eq. Further research and ongoing development, e.g. in refrigeration and air conditioning, are likely to further increase the number of low-cost options (Hendriks *et al.*, 2001a; Harnisch and Hendriks, 2000).
6 In our analysis we include both public generation and autogeneration, both in regular plants and in Combined Heat and Power (CHP) generation. Non-CO_2 emissions cover only 1% of the total greenhouse gas emissions in this sector.
7 Estimates of potential sequestration through afforestation and reforestation vary. For instance, Sathaye and Ravindranath (1998) estimated a global technical potential of 9 GtC. This is close to the estimate by Kauppi *et al.* (2001) for Latin America alone, namely about 10 GtC until 2030. We can make a rough estimate of the global cost-effective mitigation potential through afforestation and reforestation until 2020. If we opt for, say, 10 or 20 GtC, we could increase globally allowed emissions (see section 3) until 2020 by 2–3%.
8 This equals 85 GtC or 310 Gt CO2-eq until 2050.
9 In this study we do not pay any attention to the common but differentiated responsibilities for causing the climate change problem, to which Article 3.1 also refers.
10 Note that we could not incorporate the last basic principle of ‘a supportive and open international economic system’ in our calculations (Article 3.5), although we do recognize its importance for an effective international climate change mitigation.

References

Anonymous, 1995. Highest supercriticality for Skaerbaek and Nordjyland. Modern Power Systems 3, 41–43.
Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., Nicholls, R.J., Parry, M.L., Livermore, M.T.M., White, A., 2002. The consequences of CO_2 stabilisation for the impacts of climate change. Climatic Change 53, 413–446.
Babiker, M.H., Reilly, J.M., Mayer, M., Eckaus, R.S., Sue Wing, I., Hyman, R.C., 2001. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results. Massachusetts Institute of Technology, Cambridge, MA.
Berk, M.M., den Elzen, M.G.J., 2001. Options for differentiation of future commitments in climate policy: how to realise timely participation to meet stringent climate goals? Climate Policy 1, 465–480.
Blanchard, O., Criqui, C., Trommetter, M., Vinguier, L., 2001. Equity and efficiency in climate change negotiations: a scenario for world emission entitlements by 2030, Cahier de Recherche No. 26. Institut d’Economie et de Politique de l’Energie

(IEPE), Grenoble, France.
Blok, K., Phylipsen, G.J.M., Bode, J.W., 1997. The Triptique approach. Burden differentiation of CO_2 emission reduction among European Union member states. Discussion paper informal workshop for the European Union Ad Hoc Group on Climate, Utrecht University, Department of Science, Technology and Society, Zeist, The Netherlands.
CSE, 1998. Definitions of Equal Entitlements. Centre for Science and Environment, Delhi, India.
Cubasch, U., Meehl, G.A., Boer, G.J., Stouffer, R.J., Dix, M., Noda, A., Senior, C.A., Raper, S., Yap, K.S., 2001. Projections of future climate change. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P., Dai, X., Maskell, K., Johnson, C.I. (Eds), Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, pp. 525–582.
de Jager, D., Hendriks, C.A., Byers, C., van Brummelen, M., Petersdorff, C., Struker, A.H.M., Blok, K., 2001. Emission reduction of non-CO_2 greenhouse gases. Ecofys, Utrecht, TNO-MEP, Apeldoorn, Wageningen University, Wageningen, The Netherlands.
den Elzen, M.G.J., 2001. Evaluating post-Kyoto climate regimes for differentiation of commitments under Article 2 of the Climate Change Convention. Integrated Assessment 4.
Eickhout, B., den Elzen, M.G.J., van Vuuren, D.P., 2002. Emission profiles to meet climate goals. RIVM-Report 728001024. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
ETSAP, 2001. Energy Technology Systems Analysis Programme. Energy Research Foundation, Petten, The Netherlands.
European Parliament, 2001. Common Position. C5-0434/01 2001/0029 (COD) EN, 27 September 2001, Brussels.
FAO, 2002. State of the World's Forests. Food and Agriculture Organization of the United Nations, Rome.
Fischer, G., van Velthuizen, H., Shah, M., Nachtergaele, F., 2002. Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results. International Institute for Applied Systems Analysis, Laxenburg, Austria and Food and Agriculture Organization of the United Nations, Rome.
Goldemberg, J., Johansson, T.B., Reddy, A.K.N., Williams, R.H., 1988. Energy for a Sustainable World. John Wiley and Sons, New York.
Groenenberg, H., 2002. Development and convergence: a bottom-up analysis for the differentiation of commitments under the Climate Convention. Dissertation, Utrecht University, Utrecht, The Netherlands.
Groenenberg, H., Blok, K., Phylipsen, D., 2001. Differentiating commitments world wide. Global differentiation of GHG emissions reductions based on the Triptych approach – a preliminary assessment. Energy Policy 29, 1007–1030.
Gupta, J., 1999. North–South aspects of the climate change issue: towards a constructive negotiating package for developing countries. Reciel 8, 198–208.
Gupta, J., van der Werff, P., Gagnon-Lebrun, F., van Dijk, I., 2001. Bridging interest, classification and technology gaps in the climate change regime. IVAM Environmental Research UvA BV and Institute of Environmental Sciences, Free University, Amsterdam.
Harnisch, J., Hendriks, C., 2000. Economic evaluation of emission reductions of HFCs, PFCs and SF6 in Europe: contribution to the study Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change on behalf of the European Union Directorate General Environment, Ecofys, Cologne, Germany.
Hendriks, C., de Jager, D., Blok, K., de Beer, J., Harnisch, J., Joosen, S., Phylipsen, D., Kerssemeeckers, M., Byers, C., Patel, M., 2001a. Economic evaluation of sectoral emission reduction objectives for climate change. Bottom-up analysis of emission reduction potentials and costs for greenhouse gases in the EU. Updated Summary Report on Result of the Bottom-up Analysis. Ecofys, Utrecht, The Netherlands.
Hendriks, C.A., de Jager, D., de Beer, J., van Brummelen, M., Blok, K., Kerssemeeckers, M., 2001b. Economic evaluation of emission reduction of greenhouse gases in the energy supply sector in the EU. DG Environment, European Commission. Ecofys, Utrecht, the Netherlands.
IEA. 1997. CO_2 Emissions from Fuel Combustion 1972–1995. International Energy Agency, Paris.
IEA-GHG, 1999. Abatement of Methane Emissions. IEA Greenhouse Gas R&D Programme, Cheltenham, UK.
IMAGE-team, 2001. The IMAGE 2.2 Implementation of the SRES Scenarios. A Comprehensive Analysis of Emissions, Climate Change and Impacts in the 21st Century. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
Imboden, D., Roggo Voegelin, C., 2000. Die 2000 Watt-Gesellschaft. Der Mondflug des 21 Jahrhunderts. ETH Bulletin 276, Swiss Federal Institute of Technology, Zürich.
Lutz, W., 1996. The Future Population of the World: What can we Assume Today? 2nd edition. Earthscan, London.
Johansson, T.B., Kelly, H., Reddy, A.K.N., Williams, R.H., 1993. Renewable fuels and electricity for a growing world economy:

defining and achieving the potential. In: Johansson, T.B., Kelly, H., Reddy, A.K.N., Williams, R.H. (Eds), Renewable Energy: Sources for Fuels and Electricity. Island Press, Washington, DC, pp. 1–72.
Kauppi, P. *et al*., 2001. Technological and economic potential of options to enhance, maintain, and manage biological carbon reservoirs and geo-engineering. In: Metz, B., Davidson, O., Swart, R., Pan, J. (Eds), Climate Change 2001. Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
Krause, F., Bach, W., Koomey, J., 1989. Energy Policy in the Greenhouse. Vol. 1: From Warming Fate to Warming Limit: Benchmarks for a Global Climate Convention. International Project for Sustainable Energy Paths, El Cerrito, CA.
Kroeze, C., Mosier, A.R., 2000. New estimates for emissions of nitrous oxide. In: van Ham, J., Baede, A.P.M., Meyer, L.A., Ybema, R. (Eds), Non-CO_2 Greenhouse Gases: Scientific Understanding, Control, 3rd Implementation. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Lempert, R.J., Schlesinger, M.C., 2000. Robust strategies for abating climate change. Climatic Change 45, 387–401.
Luiten, E., 2001. Beyond energy efficiency. Dissertation, Department of Science, Technology and Society, Utrecht University, Utrecht, The Netherlands.
Meyer, A., 2000. Contraction and Convergence: The Global Solution to Climate Change. Green Books, Bristol, UK.
Mosier, A.R., Duxbury, J.M., Freney, J.R., Heinemeyer, O., Minami, K., Johnson, D.E., 1998. Mitigating agricultural emissions of methane. Climatic Change 40, 39–80.
Nakicenovic, N., *et al*. (Eds), 2000. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge.
Olivier, J.G.J., 2002. Emission Database EDGAR 3.2. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
Philibert, C., Pershing, J., 2001. Considering the options: climate targets for all countries. Climate Policy 1, 211–227.
Phylipsen, G.J.M., Bode, J.W., Blok, K., Merkus, H., Metz, B., 1998. A Triptych sectoral approach to burden differentiation: GHG emissions in the European bubble. Energy Policy 26, 929–943.
Rijsberman, F.R., Swart, R.J., 1990. Targets and Indicators of Climatic Change. The Stockholm Environment Institute, Stockholm.
Ringius, L., 1999. Differentiation, leaders, and fairness: negotiating climate commitments in the European Community. International Negotiations 4, 133–166.
Sathaye, J., Ravindranath, N.H., 1998. Climate change mitigation in the energy and forestry sectors of developing countries. Annual Review of Energy and Environment 23, 387–437.
Sijm, J., Jansen, J., Torvanger, A., 2001. Differentiation of mitigation commitments: the Multi-Sector Convergence approach. Climate Policy 1, 481–497.
Smith, D., 1999. First H System gas turbine planned for Baglan. Modern Power Systems 5, 39–42.
Steger, U., Puk, P., Jansen, J. (Eds), 2002. Nachhaltige Entwicklung und Innovation im Energiebereich. Kapital 5: Potentiale für die Nachhaltige Entwicklung von Energiesystemen. Springer, Heidelberg, Germany.
UN, 1997a. Framework compilation of proposals from Parties for the elements of a protocol or another legal instrument. Note by the Chairman.
UN, 1997b. Implementation of the Berlin mandate. Proposals from Parties. Note by the Secretariat.
UN, 1998. 1996 Industrial Commodity Statistics Yearbook. Production Statistics (1987–1996). United Nations Department of Economic and Social Affairs, Statistics Division, New York.
UN, 1999. Scientific and methodological aspects of the proposal by Brazil. Draft conclusions by the Chairman.
UN, 2001. Scientific and methodological aspects of the Brazilian proposal.